

AIR QUALITY MONITORING CONSIDERATIONS FOR THE MID-ATLANTIC NETWORK

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Introduction

As part of the National Park Service (NPS) Inventory and Monitoring (I&M) Program's Vital Signs scoping process, the Mid-Atlantic Network (MIDN) will evaluate the need for ambient air quality and air pollution effects monitoring in Network parks. This report contains background and summary air quality information to assist Network staff in that effort. On-site and nearby off-site ambient air quality data were used in conjunction with park-specific resource information to evaluate the following relative to the MIDN: 1) the need for additional ambient air quality monitoring at any Network park, i.e., wet deposition, dry deposition, visibility, and/or ozone monitoring, and 2) the need for air quality effects-related monitoring at any Network park. The results of this evaluation are discussed below.

The evaluation for MIDN parks relied on data collected through a number of Federal- and state-sponsored ambient air quality monitoring programs. Monitor locations, site numbers, and distances from MIDN parks are provided in Tables 1 and 2. Maps displaying monitor locations and graphics summarizing monitoring data are provided in a separate PowerPoint file as an addendum to this report.

The evaluation used products developed by the NPS Air Resources Division (ARD) specifically for the I&M Program. In 2004, the Air Resources Division (ARD) finalized an Air Quality Inventory for I&M parks. The Air Quality Inventory consists of Geographic Information System (GIS)-based maps and associated look-up tables that provide baseline values for a set of air quality parameters for all I&M parks. The values are based on averaged 1995 to 1999 data. Because ozone is a regional pollutant, in most cases the look-up table values are likely representative of ozone concentrations in a park. Greater variability, and uncertainty, may exist for deposition and visibility values, since those pollutants are more likely to be influenced by meteorological differences. Air Quality Inventory products are contained in the NPS Air Atlas (<http://www2.nature.nps.gov/air/maps/airatlas/>). NPS Air Atlas estimates for select air quality parameters for MIDN parks are provided in Appendix 1 of this report, and a description of those parameters is provided in Appendix 2.

In an ongoing project, ARD contracted with an ozone effects expert to assess the risk of ozone-induced foliar injury on sensitive vegetation in I&M parks. The risk assessments are based on NPS Air Atlas ozone values, the Palmer Z Drought Index and park vascular plant lists. The risk assessments will be posted on the ARD website in summer 2004. In the meantime, the draft risk assessment for the MIDN is attached as Appendix 3.

Wet Deposition

The National Atmospheric Deposition Program/National Trends Network (NADP/NTN) is a nationwide network of precipitation monitoring sites. The network is a cooperative effort between many different groups, including the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey, U.S. Department of Agriculture, and private entities. The NPS is a major participant in NADP/NTN, and the ARD recommends that any new wet deposition site installed in a park meet NADP/NTN siting criteria and follow NADP/NTN monitoring protocols. There are currently more than 200 NADP/NTN sites spanning the continental U.S., Alaska, Puerto Rico, and the Virgin Islands (<http://nadp.sws.uiuc.edu/>).

The purpose of the NADP/NTN network is to collect data on the chemistry of precipitation in order to monitor geographical and temporal long-term trends. The precipitation at each station is collected weekly according to strict clean-handling procedures. It is then sent to the Central Analytical Laboratory in Illinois where it is analyzed for hydrogen (acidity as pH), sulfate (SO₄), nitrate (NO₃), ammonium (NH₄), chloride, and base cations (such as calcium, magnesium, potassium and sodium). NADP/NTN's excellent quality assurance programs ensure that the data remain accurate and precise.

The NADP/NTN has also expanded its sampling to include the Mercury Deposition Network (MDN), which currently has over 35 sites. The MDN was formed in 1995 to collect weekly samples of precipitation, which are analyzed for total mercury. The objective of the MDN is to monitor the amount of mercury in precipitation on a regional basis (<http://nadp.sws.uiuc.edu/mdn/>).

The Pennsylvania Department of Environmental Protection (DEP), under a cooperative agreement with Pennsylvania State University, has maintained the Pennsylvania Atmospheric Deposition Monitoring Network since 1981. The purpose of the DEP program is to determine how much atmospheric deposition is falling in precipitation in the state (<http://www.dep.state.pa.us/dep/deputate/airwaste/aq/acidrain/acidrain.htm>). The DEP supports nine wet atmospheric deposition and six wet mercury deposition monitoring sites. The Pennsylvania Atmospheric Deposition Monitoring Network monitors the same parameters, follows the same protocols and uses the same quality assurance programs as NADP/NTN and MDN. More than half of the Pennsylvania Atmospheric Deposition Monitoring Network sites are in the NADP/NTN, and all the Pennsylvania DEP mercury monitoring sites are in the MDN.

Deposition varies with the amount of annual on-site precipitation, and is useful because it gives an indication of the total annual pollutant loading at the site. Concentration is independent of precipitation amount, therefore, it provides a better indication of whether ambient pollutant levels are increasing or decreasing over the years. In general, annual average wet deposition and concentration of SO₄, NO₃, and NH₄ are higher in the eastern than in the western U.S. At many NADP/NTN sites across the U.S., concentration and deposition of SO₄ have declined in recent years as sulfur dioxide emissions have decreased. Trends have been variable for NO₃ and NH₄, with concentration and deposition at various sites increasing, decreasing, or showing no overall change.

Shenandoah National Park (NP) and Valley Forge National Historical Park (NHP) have wet deposition monitors on-site; the rest of the parks in the MIDN have either a Pennsylvania Atmospheric Deposition Monitoring Network or a NADP/NTN monitor within 90 km. The 2002 NADP/NTN and Pennsylvania Atmospheric Deposition Monitoring Network wet deposition

values for the MIDN were similar, and were consistent with the 1995 through 1999 Network averages contained in the NPS Air Atlas. Sulfate, NO₃ and NH₄ wet deposition ranged from about 15 to 22 kilograms per hectare per year (kg/ha/yr), 9 to 16 kg/ha/yr, and 1.9 to 3.5 kg/ha/yr, respectively. Converted to sulfur (S) and nitrogen (N), the ranges for the NADP/NTN and Pennsylvania Atmospheric Deposition Monitoring Network values were 5.0 to 7.3 kg/ha/yr for wet S deposition, and 3.5 to 6.3 kg/ha/yr for wet N deposition. The Air Atlas wet deposition values for MIDN parks were 3.7 to 5.6 kg/ha/yr for S and 3.0 to 4.5 kg/ha/yr for N. The NADP/NTN and Pennsylvania Atmospheric Deposition Monitoring Network wet concentration values for SO₄, NO₃ and NH₄ ranged from about 1.3 to 2.1 milligrams per liter (mg/l), 0.8 to 1.5 mg/l, and 0.16 to 0.34 mg/l, respectively. Trend results for NADP/NTN and Pennsylvania Atmospheric Deposition Monitoring Network sites in and near MIDN parks are summarized below.

Arendtsville, PA

An NADP/NTN site was installed at Arendtsville, Pennsylvania (PA00), in 1999. Sufficient data are not yet available to characterize pollutant trends at the site.

Valley Forge NHP, PA

A Pennsylvania Atmospheric Deposition Monitoring Network monitor has been operating at Valley Forge NHP (PA60) since 1982. Data show wet concentration and deposition of SO₄ have decreased substantially, wet concentration and deposition of NO₃ have decreased slightly, and wet concentration and deposition of NH₄ have increased.

Charlottesville, VA

Charlottesville, Virginia, has had an NADP/NTN site (VA00) since 1984. Site data show wet concentration and deposition of SO₄, wet concentration and deposition of NO₃, and wet concentration and deposition of NH₄ have decreased since 1990.

Eggleston, VA

The NADP/NTN site has been operating in Eggleston, Virginia (VA13 (Horton Station)), since 1978. Trend data are only available since 1987. Data showed a decrease in wet SO₄ concentration and deposition, but no apparent trend in concentration and deposition of NO₃ or NH₄.

Green Bay, VA

An NADP/NTN site was installed at Green Bay, Virginia (VA24 (Prince Edward)), in 1999. Trend data are not yet available for the site.

Natural Bridge, VA

An NADP/NTN monitor was installed at Natural Bridge, Virginia (VA99), in 2002. Trend data are not yet available from the site.

Shenandoah NP, VA

The NADP/NTN site at Big Meadows, Shenandoah NP, Virginia (VA28), has been operating since 1981. A review of site data shows concentration and deposition of wet SO₄ have decreased, as has deposition of wet NO₃. There has been no apparent trend in concentration of wet NO₃, concentration of wet NH₄, or deposition of wet NH₄.

The four Pennsylvania MIDN parks, Shenandoah NP and Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park (NMP) have MDN monitors on-site or within 45 km. There is no MDN monitor within 100 km of Appomattox Court House NHP, Booker T. Washington National Monument (NM), Petersburg National Battlefield (NB) or Richmond National Battlefield Park (NBP). Trend analyses have not yet been performed for MDN sites due to the relatively short time that sites have been in operation. The MDN site in Arendtsville, Pennsylvania (PA00), has been operating since 2000, the site in Valley Forge NHP, Pennsylvania (PA60), has been operating since 1999, and sites in Culpeper (VA08) and Big Meadows, Shenandoah NP, Virginia (VA28), were installed in 2002. MDN deposition maps show that, similar to SO₄ and NO₃, wet mercury deposition is higher in the eastern U.S. than in the western U.S. Highest wet mercury deposition values are consistently monitored at sites in Florida and along the Gulf of Mexico.

Dry Deposition

The Clean Air Status and Trends Network (CASTNet) is the nation's primary source for atmospheric data to estimate dry acidic deposition (<http://www.epa.gov/castnet/>). Established in 1987, CASTNet now comprises over 70 monitoring stations across the U.S. The majority of the monitoring stations are operated by EPA; however, approximately 20 stations are operated by the NPS in cooperation with EPA. Each CASTNet dry deposition station measures weekly average atmospheric concentrations of SO₄, NO₃, NH₄, sulfur dioxide, and nitric acid; hourly concentrations of ambient ozone; and some meteorological parameters. Dry deposition rates are calculated using atmospheric pollutant concentrations, meteorological data, and information on land use, vegetation, and surface conditions. CASTNet complements the database compiled by NADP/NTN; therefore, CASTNet sites are located at or near NADP/NTN sites. Dry deposition monitoring is more difficult, and more expensive, than wet deposition monitoring; consequently, there are fewer CASTNet than NADP/NTN sites nationwide. Due to the small number of CASTNet sites, it is not possible to develop dry deposition isopleth maps such as those produced by NADP/NTN. Because CASTNet uses different monitoring and reporting techniques than NADP/NTN, the dry deposition amounts are reported as S and N, rather than SO₄, NO₃ and NH₄. In addition, because CASTNet calculates dry deposition based on estimated deposition velocities, there is greater uncertainty in the reported values.

Shenandoah NP has a CASTNet monitor on-site; all other MIDN parks have a monitor within 90 km. Data summaries and trend analyses for CASTNet sites near MIDN parks are provided below. All trend analyses cover the timeframe of 1989 through 2001.

Washington Crossing, NJ

The Washington Crossing, New Jersey, CASTNet site (WSP144) data showed decreasing trends in both dry S deposition and dry N deposition. Total S deposition at Washington Crossing was composed of 47 percent dry deposition and 53 percent wet deposition, while total N deposition was 35 percent dry and 65 percent wet.

Arendtsville, PA

The CASTNet data from Arendtsville, Pennsylvania (ARE128), showed a decrease in dry S deposition but no apparent trend in dry N deposition. According to CASTNet, total S deposition at the site consisted of 54 percent wet and 46 percent dry deposition, while total N deposition was 64 percent wet and 36 percent dry.

Eggleston, VA

Data from the Eggleston, Virginia, CASTNet site (VPI120 (Horton Station)) showed a decreasing trend in dry S deposition, but no apparent trend in dry N deposition. Total S deposition at the site was composed of 48 percent dry deposition and 52 percent wet deposition, while total N deposition was 48 percent dry and 52 percent wet.

Green Bay, VA

The CASTNet site at Green Bay, Virginia (PED108 (Prince Edward)), showed decreasing trends in both dry S deposition and dry N deposition. Total S deposition at the site was composed of 32 percent dry deposition and 68 percent wet deposition, while total N deposition was 33 percent dry and 67 percent wet.

Shenandoah NP, VA

The Shenandoah NP, Virginia, CASTNet site (SHN418) data showed a decrease in dry S deposition but no apparent trend in dry N deposition. CASTNet estimated total S deposition at Shenandoah NP was 60 percent wet and 40 percent dry, while total N deposition was 56 percent wet and 44 percent dry.

Surface Water and Fish Tissue Chemistry

It is generally accepted that surface waters with a pH below 6.0 and an acid neutralizing capacity (ANC) below 100 microequivalents per liter ($\mu\text{eq/l}$) are sensitive to acidification from atmospheric deposition. For this evaluation, the NPS Water Resources Division's (WRD) *Baseline Water Quality Data Inventory and Analysis* reports were reviewed for all MIDN parks except Shenandoah NP. For Shenandoah NP, the discussion is based on review of a comprehensive air quality and air pollution effects assessment which was completed for the park in 2003 (NPS. 2003. *Assessment of Air Quality and Related Values in Shenandoah National Park*. Technical Report NPS/NERCHAL/NRTR-03/090; http://www.nps.gov/shen/SHEN_IM/inv_references.htm#air). In addition, state agency and the NPS Research Permit and Reporting System websites were reviewed for reports of any additional, relevant surface water chemistry data. The websites were also reviewed for information pertaining to any chemical analyses conducted on aquatic biota collected in park lakes, rivers, and streams. The results of the review are summarized below.

Pennsylvania has a general, statewide fish consumption advisory to limit ingestion of contaminants from untested fish. In addition, more stringent advisories are in effect for a number of lakes and rivers in the Delaware, Ohio, Potomac and Susquehanna River Basins. These advisories are primarily for mercury, but in some locations, polychlorinated biphenyls (PCBs) or chlordanes are also of concern

(http://sites.state.pa.us/PA_Exec/Fish_Boat/fishpub/summary/sumconsumption.pdf). In Valley Creek at Valley Forge, it is unlawful to kill or possess any fish species due to PCB contamination. In Virginia, fish consumption advisories are in effect for the James River for

kepone and PCBs and in the Shenandoah River for PCBs and mercury (http://www.vdh.state.va.us/HHControl/fishing_advisories.htm).

Appomattox Court House NHP

A review of the 1998 *Baseline Water Quality Data Inventory and Analysis* report for Appomattox Court House NHP indicated no water quality data have been collected inside the park, so acid sensitivity of park surface waters is unknown.

Booker T. Washington NM

The 1997 *Baseline Water Quality Data Inventory and Analysis* report for Booker T. Washington NM contains no data collected within the park boundary. Data collected from 1991 to 1995 at a location on Gill's Creek outside the park had an average pH of 7.5. The NPS Research Permit and Reporting System described an annual water quality monitoring program in the park. Reported average pH values for Gill's Creek and Jack-O-Lantern Branch were 6.8 and 7.3, respectively, indicating surface waters in the park are likely not sensitive to acidification from atmospheric deposition.

Fredericksburg and Spotsylvania County Battlefields Memorial NMP

The 2000 *Baseline Water Quality Data Inventory and Analysis* report for Fredericksburg and Spotsylvania County Battlefields Memorial NMP contains data collected in the park between 1991 and 1996. Average pH values ranged from about 5.5 in some small tributaries to about 6.5 in the larger streams. The low pH values indicate some of the tributaries could be acid-sensitive, but without ANC data, it is not possible to assess their sensitivity.

Gettysburg NMP and Eisenhower National Historic Site (NHS)

The 1999 *Baseline Water Quality Data Inventory and Analysis* report for Gettysburg NMP and Eisenhower NHS contains data collected at numerous springs and streams in both parks between 1972 and 1980. In addition, the NPS Research Permit and Reporting System discussed water quality data collected between 1991 and 1998 in association with fish and stream invertebrate surveys. All data indicated surface waters in the parks are well-buffered and not susceptible to acidification from atmospheric deposition, e.g., the parks had average pH values of about 7.5 and average ANC values of about 800 µeq/l.

Hopewell Furnace NHS

A review of the 1998 *Baseline Water Quality Data Inventory and Analysis* report for Hopewell Furnace NHS indicated surface water chemistry data have been collected in the park since 1991 at French Creek, Baptism Creek and Sprout Run. All data suggested surface waters in the parks are well-buffered and not susceptible to acidification from atmospheric deposition, e.g., the park had average pH values of about 7.0 and average ANC values of about 150 µeq/l.

Petersburg NB

The 1997 *Baseline Water Quality Data Inventory and Analysis* report for Petersburg NB contains 1996 data for Harrison Creek and Poor Creek. The data indicate surface waters in the park are well-buffered and not susceptible to acidification from atmospheric deposition, e.g., the creeks had average pH values of about 6.8.

Richmond NBP

A review of the 1999 *Baseline Water Quality Data Inventory and Analysis* report for Richmond NBP showed limited in-park data collected prior to 1999, most of which were collected to assess the presence of landfill leachate in park streams. The NPS Research Permit and Reporting System discussed data collected at 15 sites in the park between 2001 and 2002. The data indicated most sites had pH values below the state standard. The low values were attributed to high concentrations of organic acids from park wetlands. The Drewry's Bluff stream, however, had high ANC values. The data suggested park surface waters are not susceptible to acidification from atmospheric deposition.

Shenandoah NP

The 2003 report, *Assessment of Air Quality and Related Values in Shenandoah National Park*, describes how stream water chemistry has been monitored in the park since 1979 as part of the Shenandoah Watershed Assessment Study. The study was designed to improve understanding of watershed processes and biogeochemistry in the park. Fourteen watersheds are currently monitored on a regular basis. The data indicate underlying bedrock plays an important role in watershed acid sensitivity in Shenandoah NP. Many of the streams on the acid-sensitive siliciclastic bedrock have experienced chronic and episodic acidification, and some have lost acid-sensitive fish and invertebrate species. A number of the streams on sensitive bedrock have an ANC below 20 µeq/l; the average estimated loss of ANC in these streams since pre-industrial times is 73 µeq/l. Modeling suggested that even with an immediate substantial decrease in atmospheric deposition, it would take decades for park streams to regain buffering capacity.

Valley Forge NHP

The 2003 *Baseline Water Quality Data Inventory and Analysis* report for Valley Forge NHP includes data collected from rivers, streams, creeks, springs, and ponds in the park between 1974 and 1998. Average pH values ranged from 6.0 to 8.6. The data indicated surface waters in Valley Forge NHP are not sensitive to acidification from atmospheric deposition.

Particulate Matter

Small or "fine" particles in the air, typically those less than 2.5 microns in diameter, PM_{2.5}, are a leading cause of human respiratory illness. Particles are present everywhere, but high concentrations and/or specific types have been found to present a serious danger to human health. Fine particles in the air are also the main contributor to human-caused visibility impairment. The particles not only decrease the distance one can see; they also reduce the colors and clarity of scenic vistas.

The current human-health based National Ambient Air Quality Standards (NAAQS) for particulate matter (set by the EPA) are for particles 10 microns or less in diameter (PM₁₀). Areas where air quality exceeds the NAAQS for PM₁₀ are designated "nonattainment" for that pollutant. There are PM₁₀ monitors within 25 km of all MIDN parks except Appomattox Court House NHP, Eisenhower NHS, Gettysburg NMP, and Petersburg NB. No designated PM₁₀ nonattainment areas are located near MIDN parks (<http://www.epa.gov/air/data/index.html>).

In 1997, EPA finalized new stricter NAAQS for particulate matter based on PM_{2.5}. Nationwide PM_{2.5} monitoring was initiated in 1999; nonattainment areas will not be designated until December 2004. There are PM_{2.5} monitors within 30 km of all MIDN parks except

Fredericksburg and Spotsylvania County Battlefields Memorial NMP. Monitoring data for 2000 through 2002 indicate there will be no PM_{2.5} nonattainment areas near MIDN parks (http://www.epa.gov/ttn/naaqs/pm/pm25_tech_info.html).

Visibility

In 1985, in response to the mandates of the Clean Air Act, Federal and regional/state organizations established the Interagency Monitoring of Protected Visual Environments (IMPROVE) program to protect visibility in Class I air quality areas. Class I areas are national parks greater than 5,000 acres and wilderness areas greater than 6,000 acres, that were established prior to August 7, 1977. All other NPS areas are designated Class II. The objectives of the IMPROVE program are to: establish current visibility conditions in all Class I areas, identify pollutants (particles and gases) and emission sources responsible for existing man-made visibility impairment, and document long-term trends in visibility. The IMPROVE network is designed to assess regional visibility; standard operation does not identify individual sources that impair visibility at a monitoring site.

In 1999, there were 30 official IMPROVE sites and 40 protocol sites. Because of recently enacted Regional Haze regulations that require improving visibility in Class I areas, the number of visibility monitors has increased. Protocol sites were upgraded to full IMPROVE sites and 80 new sites were added to the IMPROVE network. While the IMPROVE program has focused on Class I air quality areas, a great deal of visibility monitoring has been conducted in Class II areas. Installation and annual operating costs for a full IMPROVE site are expensive. The ARD is currently developing a monitoring protocol for less-expensive view monitoring using a digital camera. While this type of monitoring would not be adequate for regulatory purposes, it is useful for documenting visibility conditions and trends and provides an excellent means of sharing that information with the public.

Shenandoah NP has an IMPROVE monitor on-site. Appomattox Court House NHP, Booker T. Washington NM, Eisenhower NHS, Fredericksburg and Spotsylvania County Battlefields Memorial NMP and Gettysburg NMP all have an IMPROVE monitor within 75 km. The IMPROVE sites in the region are as follows: Edwin B. Forsythe National Wildlife Refuge (NWR), New Jersey (Brigantine, BRIG1), operating since 1991; New Holland, North Carolina (Swanquarter NWR, SWAN1), operating since 2000; Arendtsville, Pennsylvania (AREN1), operating since 2001; Natural Bridge, Virginia (James River Face Wilderness Area, JARI1), operating since 2000; Shenandoah NP, Virginia (SHEN1), operating since 1988; and Washington, D.C. (WASH1), operating since 1988.

IMPROVE provides maps of visibility conditions at all monitoring sites, pie charts of the pollutants that contribute to visibility impairment at each site, and trend data for sites that have been operating 10 years or longer (<http://vista.cira.colostate.edu/views/>). One measurement used to report visibility is light extinction, or b_{ext} , reported in inverse megameters (Mm^{-1}). Light extinction occurs when particles in the air scatter or absorb light; extinction generally increases as particle concentrations in the air increase. Therefore, the higher the b_{ext} , the worse the visibility. The Regional Haze regulations require improvements in visibility on both the best (clearest), and the worst (haziest), days. In general, visibility is much better in the western, than in the eastern, U.S.

2002 IMPROVE data indicated b_{ext} at MIDN parks on the best visibility days ranged from 26 to 45 Mm^{-1} . On the worst visibility days, b_{ext} at Network parks ranged from 139 to 191 Mm^{-1} . These values are consistent with the 1995 to 1999 values provided in the NPS Air Atlas, i.e., 27 to 39 Mm^{-1} on the best visibility days and 171 to 190 Mm^{-1} on the worst visibility days. IMPROVE data showed that at all six sites in the region, on an annual basis, impairment in 2002 was due primarily to ammonium sulfate (sources include coal combustion and oil refineries). The remainder was due to ammonium nitrate (sources include coal and natural gas combustion and automobiles), organics (sources include automobiles), elemental carbon (sources include wood burning) and coarse mass (larger than $\text{PM}_{2.5}$; sources unknown). Trend data are available for Edwin B. Forsythe NWR, Shenandoah NP, and Washington, D.C. The data indicate an improvement in visibility at all three sites on both the best and the worst visibility days.

Ozone

Ozone is created by a chemical reaction between oxides of nitrogen and volatile organic compounds in the presence of heat and sunlight. Some major sources of ozone-forming chemicals are motor vehicle exhaust and industrial emissions, gasoline vapors, and chemical solvents. High ozone concentrations cause respiratory problems in humans, and are a particular concern for those who are engaging in strenuous aerobic activity, such as hiking. Ozone also damages sensitive plant species. It injures plant leaves by causing a visible spotting or “stipple” on the upper surface of the leaves. Ozone can affect plant physiology by reducing growth, increasing susceptibility to disease, and increasing senescence.

Shenandoah NP has an ozone monitor on-site. With the exception of Appomattox Court House NHP, all other MIDN parks have a monitor within 30 km (<http://www.epa.gov/air/data/index.html>). The Pennsylvania counties that contain Eisenhower NHS, Gettysburg NMP and Valley Forge NHP are designated nonattainment for the existing 1-hour ozone NAAQS. There are no 1-hour ozone nonattainment areas in Virginia. EPA recently established a new NAAQS for ozone, which is based on an 8-hour ozone concentration, and this summer they published their proposed list of nonattainment areas (<http://www.epa.gov/ttn/naaqs/ozone/index.html>). With the exception of Appomattox Court House NHP, Booker T. Washington NM and Shenandoah NP, all MIDN parks are in proposed 8-hour ozone nonattainment areas. Based on the 1995 to 1999 ozone values contained in the Air Atlas, all MIDN parks could be nonattainment for the 8-hour ozone NAAQS.

The NPS focuses on plant sensitivity to ozone for a couple of reasons. First, ozone is a regional pollutant and is, therefore, more likely to affect park resources than other gaseous pollutants such as sulfur dioxide and nitrogen oxide which quickly convert to other compounds. Second, the literature on ozone sensitivity is more recent and more reliable than that for other pollutants. The ARD contracted with an ozone effects expert from Cornell University to perform ozone injury risk assessments for all parks in the NPS I&M program. The risk assessments relied on the ozone concentration data provided in Air Atlas, vascular plant lists contained in NPSpecies, a list of ozone-sensitive vascular plant species developed at a 2003 expert workshop convened by the ARD (<http://www2.nature.nps.gov/air/Pubs/index.htm>), and the Palmer Z Index, which is used to indicate soil moisture status. Note that the ARD workshop report provides a general guide to ozone sensitivity. Differences in plant genetics, weather conditions, soil water availability, and ozone concentrations will affect whether or not a species exhibits injury in a park. In particular, studies have shown that plants will not take up ozone unless there is sufficient soil moisture. The risk assessments for the MIDN parks (Appendix 3) indicate the risk of ozone-induced foliar

injury of sensitive vegetation is moderate at Appomattox Court House NHP, Booker T. Washington NM, Petersburg NB, Richmond NBP and Shenandoah NP, while the risk is high at the rest of the Network parks.

A number of ozone injury studies have been conducted at Shenandoah NP. Foliar injury has been observed on sensitive species including milkweed (*Asclepias* spp.), black cherry (*Prunus serotina*), and yellow poplar (*Liriodendron tulipifera*). Ozone injury surveys were conducted on milkweed in Fredericksburg and Spotsylvania County Battlefields Memorial NMP from 1986 through 1991. Injury was detected each year; however, the amount and severity of injury varied by year.

The U.S.D.A. Forest Service Forest Health Monitoring (FHM) program administers a nationwide biomonitoring program in partnership with the EPA and states. Ozone injury surveys are one component of the FHM program. According to a recent publication, FHM surveys in 2000 detected ozone injury on plots in the vicinity of all parks in the MIDN with the exception of Appomattox Court House NHP and Booker T. Washington NM (Smith et al. 2003. *Environmental Monitoring and Assessment* 87:271-291). Because FHM does not provide plot location information, it is not known how close the plots are to NPS lands.

Conclusions

All MIDN parks have both wet and dry deposition monitors on-site or within 90 km. Most likely, this coverage is adequate for Network parks. The four Pennsylvania MIDN parks, Shenandoah NP, and Fredericksburg and Spotsylvania County Battlefields Memorial NMP have MDN monitors on-site or within 45 km. Mercury deposition monitoring may not be adequate for the other four Network parks.

Some streams in Shenandoah NP have documented sensitivity to atmospheric deposition. With the exception of Appomattox Court House NHP and Fredericksburg and Spotsylvania County Battlefields Memorial NMP, where sensitivity is unknown, surface waters in the rest of the MIDN parks appear well-buffered. Given the fish consumption advisories for mercury, PCBs and chlordane in Pennsylvania and Virginia, the MIDN may want to consider long-term monitoring of contaminant levels in fish or other biota.

Particulate matter is monitored within 30 km of all MIDN parks. IMPROVE sites are located within 75 km of all Network parks except Hopewell Furnace NHS, Petersburg NB, Richmond NBP, and Valley Forge NHP. If visibility impairment is a particular concern for any Network park, the MIDN may want to consider installing a digital camera to record and interpret visibility conditions.

Except for Appomattox Court House NHP, all MIDN parks have an ozone monitor on-site or within 30 km. With the exception of Appomattox Court House NHP, Booker T. Washington NM and Shenandoah NP, all MIDN parks are in proposed 8-hour ozone nonattainment areas. Based on the 1995 to 1999 ozone values contained in the Air Atlas, all MIDN parks could be nonattainment for the 8-hour ozone NAAQS. The MIDN may want to consider installing a portable ozone monitor in Appomattox Court House NHP to determine if interpolated Air Atlas ozone estimates accurately reflect nonattainment of the NAAQS at the park (see attached *Ozone Monitoring Protocol*).

The ozone injury risk assessments funded by the NPS ARD indicate a moderate to high risk of ozone injury of sensitive vegetation in all MIDN parks. The Network may want to consider conducting foliar injury surveys in Network parks.

Table 1. Summary of Deposition Data Collected in and near National Park Service Units in the Mid-Atlantic Network

PARK	NADP/NTN		CASTNet		MDN	
	LOCATION	SITE #	LOCATION	SITE #	LOCATION	SITE #
APPO	Green Bay, VA 50 km SE	VA24	Green Bay, VA 50 km SE	PED108	Shenandoah NP, VA 145 km N	VA28
	Natural Bridge, VA 75 km NW	VA99			Culpeper, VA 145 km NE	VA08
BOWA	Natural Bridge, VA 60 km N	VA99	Eggleston, VA 80 km NW	VPI120	Shenandoah NP, VA 190 km NE	VA28
	Eggleston, VA 80 km NW	VA13			Culpeper, VA 210 km NE	VA08
EISE	Arendtsville, PA 15 km N	PA00	Arendtsville, PA 15 km N	ARE128	Arendtsville, PA 15 km N	PA00
FRSP	Charlottesville, VA 75 km SW	VA00	Shenandoah NP, VA 85 km NW	SHN418	Culpeper, VA 45 km NW	VA08
	Shenandoah NP, VA 85 km NW	VA28			Shenandoah NP, VA 85 km NW	VA28
GETT	Arendtsville, PA 10 km N	PA00	Arendtsville, PA 10 km N	ARE128	Arendtsville, PA 10 km N	PA00
HOFU	Valley Forge NHP, PA 25 km SE	PA60	Washington Crossing, NJ 75 km E	WSP144	Valley Forge NHP, PA 25 km SE	PA60
PETE	Green Bay, VA 85 km W	VA24	Green Bay, VA 85 km W	PED108	Culpeper, VA 150 km NW	VA08
					Shenandoah NP, VA 170 km NW	VA28
RICH	Green Bay, VA 90 km SW	VA24	Green Bay, VA 90 km SW	PED108	Culpeper, VA 120 km NW	VA08
					Shenandoah NP, VA	VA28

					145 km NW	
SHEN	On-site, Big Meadows	VA28	On-site, Big Meadows	SHN418	On-site, Big Meadows	VA28
VAFO	On-site*	PA60	Washington Crossing, NJ 55 km NE	WSP144	On-site	PA60

NADP/NTN = National Atmospheric Deposition Program/National Trends Network

CASTNet = Clean Air Status and Trends Network

MDN = Mercury Deposition Network

APPO = Appomattox Court House NHP

BOWA = Booker T. Washington NM

EISE = Eisenhower NHS

FRSP = Fredericksburg and Spotsylvania County Battlefields Memorial NMP

GETT = Gettysburg NMP

HOFU = Hopewell Furnace NHS

PETE = Petersburg NB

RICH = Richmond NBP

SHEN = Shenandoah NP

VAFO = Valley Forge NHP

*VAFO is a wet deposition site in the Pennsylvania Atmospheric Deposition Monitoring Network, but is not in NADP

August 2004

Table 2. Summary of Ozone, IMPROVE and PM Data Collected in and near NPS Units in the Mid-Atlantic Network

PARK	OZONE		IMPROVE		PM	
	LOCATION	SITE #	LOCATION	SITE #	LOCATION	SITE #
APPO			Natural Bridge, VA (James River Face WA) 75 km NW	JARI1	Lynchburg, VA 30 km W (PM _{2.5})	51-680-0015-88101
BOWA	Vinton, VA 25 km NW	51-161-1004-44201	Natural Bridge, VA (James River Face WA) 60 km N	JARI1	Roanoke, VA 25 km NW (PM _{2.5} and PM ₁₀)	51-770-0014-88101 and 81102
EISE	Pennsylvania State University Research Orchard, Adams County, PA Within 25 km N	42-001-0002-44201	Arendtsville, PA 15 km N	AREN1	Arendtsville, PA 15 km N (PM _{2.5})	42-001-0001-88101
	Franklin County, PA Within 25 km NW	42-055-0001-44201				
FRSP	Phelps Wildlife Management Area, VA Within 30 km	51-061-0002-44201	Washington, D.C. 75 km N	WASH1	Fredericksburg, VA Within 10 km (PM ₁₀)	51-630-0004-81102
	Caroline County, VA Within 30 km	51-033-0001-44201	Shenandoah NP, VA 85 km NW	SHEN1		
	Stafford County, VA Within 30 km	51-179-0001-44201				
GETT	Pennsylvania State University Research Orchard, Adams	42-001-0002-44201	Arendtsville, PA 10 km N	AREN1	Arendtsville, PA 10 km N (PM _{2.5})	42-001-0001-88101

	County, PA Within 20 km N					
	Franklin County, PA Within 25 km NW	42-055- 0001- 44201				
HOFU	Reading, PA 20 km NW	42-011- 0009- 44201	Arendtsville, PA 135 km SW	AREN1	Reading, PA 20 km NW (PM _{2.5} and PM ₁₀)	42-011- 0009- 88101 and 81102
			Edwin B. Forsythe NWR (Brigantine WA), NJ 145 km SE	BRIG1		
PETE	Shirley Plantation, Charles City County, VA 10 km NE	51-036- 0002- 44201	Shenandoah NP, VA 170 km NW	SHEN1	Shirley Plantation, Charles City County, VA 10 km NE (PM _{2.5})	51-036- 0002- 88101
	Chesterfield County, VA 30 km NW	51-041- 0004- 44201	New Holland, NC (Swanquarter NWR) 200 km SE	SWAN1		
			Natural Bridge, VA (James River Face WA) 200 km NW	JARI1		

RICH	Richmond, VA 12 km N	51-087- 0014- 44201	Shenandoah NP, VA 145 km NW	SHEN1	Shirley Plantation, Charles City County, VA 12 km SE (PM _{2.5})	51-036- 0002- 88101
	Shirley Plantation, Charles City County, VA 12 km SE	51-036- 0002- 44201	Natural Bridge, VA (James River Face WA) 190 km W	JARI1	Richmond, VA Within 15 km (PM _{2.5} and PM ₁₀)	51-760- 0020- 88101 and 81102
	Mechanicsville,	51-085-	New Holland,	SWAN1		

	VA 20 km N	0003- 44201	NC (Swanquarter NWR) 230 km SE			
	Chesterfield County, VA 25 km SW	51-041- 0004- 44201				
SHEN	On-site, Big Meadows	51-113- 0003- 44201	On-site, Big Meadows	SHEN1	Front Royal, VA Within 5 km (PM ₁₀)	51-187- 0004- 81102
					Luray, VA Within 15 km (PM _{2.5})	51-139- 0004- 88101
					Harrisonburg, VA 20 km NW (PM ₁₀)	51-165- 0002- 81102
					Harrisonburg, VA 20 km NW (PM ₁₀)	51-165- 0003- 81102
					Culpeper, VA 30 km SE (PM ₁₀)	51-047- 0002- 81102
					Charlottesville, VA 30 km SE (PM ₁₀)	51-540- 0002- 81102

VAFO	Norristown, PA Within 5 km	42-091- 0013- 44201	Edwin B. Forsythe NWR (Brigantine WA), NJ 115 km SE	BRIG1	Norristown, PA Within 5 km (PM _{2.5} and PM ₁₀)	42-091- 0013- 88101 and 81102
			Arendtsville, PA 155 km SW	AREN1		

IMPROVE = Interagency Monitoring of Protected Visual Environments Visibility Monitoring Program

PM₁₀ = Particulate matter less than 10 microns in diameter

PM_{2.5} = Particulate matter less than 2.5 microns in diameter

APPO = Appomattox Court House NHP

BOWA = Booker T. Washington NM

EISE = Eisenhower NHS

FRSP = Fredericksburg and Spotsylvania County Battlefields Memorial NMP
GETT = Gettysburg NMP
HOFU = Hopewell Furnace NHS
PETE = Petersburg NB
RICH = Richmond NBP
SHEN = Shenandoah NP
VAFO = Valley Forge NHP
WA = Wilderness Area
NWR = U.S. Fish and Wildlife Service National Wildlife Refuge

August 2004

Appendix 1. Air Atlas Pollution Estimates

Mid-Atlantic Network																				
	Ozone -----							Wet Deposition NADP -----			Visibility Mm-1 Mm-1									
Park	2nd	Hi	1hr	4th	Hi	8hr	#8hr > 85	#1hr > 100	Sum06	3 Mo	Total S	kg/Ha	Total N	kg/Ha	Rbext	Clear	Rbext	Hazy		
APCO			112.5			87.4		8.0		14.1		27.4		3.73		3.04		38		189
BOWA			111.1			86.2		6.9		11.6		27.9		3.86		3.08		39		190
EISE			123.3			93.5		12.1		27.6		34.6		4.87		3.95		30		183
FRSP			120.8			90.6		10.1		22.4		31.6		4.96		4.03		29		185
GETT			123.3			93.5		12.1		27.6		34.4		4.87		3.95		30		183
HOFU			128.2			95.7		12.3		34.4		28.7		4.47		3.80		32		172
PETE			116.9			88.9		8.8		16.8		32.8		3.93		3.25		33		185
RICH			119.8			89.9		9.7		19.7		34.3		4.18		3.44		31		185
SHEN			115.4			88.7		8.1		16.6		36.7		5.56		4.45		27		185
VAFO			129.3			96.2		12.7		36.7		28.3		4.31		3.68		32		171

Appendix 2. Description of Parameters Used in Air Atlas Summary Tables

The Air Atlas is a mini-GIS tool available on the Internet that provides national maps and an associated look-up table with baseline values of air quality parameters for all Inventory and Monitoring (I&M) parks in the U.S. The values are based on averaged 1995-1999 data. Air Atlas was produced by the National Park Service Air Resources Division (ARD) in association with the University of Denver. Air Atlas will serve as the Air Inventory for the parks and is available on the Internet at <http://www2.nature.nps.gov/ard/gas/> (see section called *Air Atlas*).

The estimated air quality values provided in the look-up table are based on the center of the polygon defining the park or multiple units of the park. Because ozone is a regional pollutant, in most cases the look-up table values are likely representative of ozone concentrations throughout the park. Greater variability may exist for other parameters, such as deposition and visibility. In the future, the full Air Atlas dataset will be available on the internet, and users of ArcView and ArcGIS will be able to obtain air quality values for multiple points in a park by entering the latitude and longitude coordinates.

Air Atlas contains a comprehensive set of air quality parameters for all I&M parks. In addition, ARD has prepared a summary table that includes a select group of air quality parameters for each I&M network. The summary version is intended to provide parks with a synopsis useful for characterizing air quality conditions. Air quality parameters selected for the summary version are described below.

Ozone Parameters

Ozone can be expressed as concentration or cumulative dose. Relevant concentration and dose parameters include:

2nd Hi 1-hr: expressed in parts per billion (ppb), this value is the 2nd highest hourly value in a year and can be compared to the former Environmental Protection Agency (EPA) human health-based standard for ozone of 125 ppb (0.12 ppm).

4th Hi 8-hr: expressed in parts per billion (ppb), this value is the average hourly value in the 4th highest 8 hour period and can be compared to the present EPA human health-based standard for ozone of 85 ppb (0.08 ppm).

8 hrs > 85 ppb: indicates how often the site would exceed the present ozone standard.

1 hr > 100 ppb: indicates how often the site experiences high ozone concentrations; high concentrations contribute to vegetation (foliar) injury in sensitive plant species.

SUM06_3Mo: The running 90-day maximum sum of the 0800-2000 hourly concentrations of ozone equal to or greater than 0.06 ppm; represents cumulative exposure dose of ozone to plants.

Ozone is one of the most widespread air pollutants. Ozone is not emitted directly from smokestacks or vehicles, but is formed when other pollutants, primarily nitrogen oxides and volatile organic compounds, react in the atmosphere in the presence of sunlight, usually during the warm summer months. In addition to harming human health, ozone is phytotoxic, and causes considerable damage to vegetation throughout the world, including agricultural crops and native

plants in natural ecosystems. The Environmental Protection Agency has established an ozone standard to protect human health; however, EPA has not set a standard to protect vegetation and there is much evidence to suggest that the human health-based standard is not protective of sensitive vegetation.

Ozone enters plants through leaf stomata and oxidizes plant tissue, causing changes in biochemical and physiological processes. Both visible foliar injury (e.g., stipple and chlorosis) and growth effects (e.g., premature leaf loss, reduced photosynthesis, and reduced leaf, root, and total dry weights) can occur in sensitive plant species. In a natural ecosystem, many other factors can ameliorate or magnify the extent of ozone injury at various times and places such as soil moisture, presence of other air pollutants, insects or diseases, and other environmental stresses.

Ozone injury can be induced by a sufficiently high seasonal dose of ozone (expressed as SUM06, in ppm-hrs), high peak concentrations of ozone (expressed in ppb), or a combination of both. Ozone effects to natural vegetation have been documented throughout the country, particularly in many areas of the East and in California. For sensitive natural vegetation in the East, researchers have recommended SUM06 effects endpoints of 8-12 ppm-hrs for foliar injury and 10-15 ppm-hrs for growth effects on tree seedlings in natural forest stands. In the West (Lassen Volcanic, Sequoia/Kings Canyon, and Yosemite NPs), researchers have found that foliar injury on ponderosa and Jeffrey pines ranges from about 15-50 percent at ozone values between 25-30 ppm-hrs. Sites with values above these endpoints may be at risk for vegetation injury if sensitive species are present. However, to adequately assess risk, other factors, including temperature and soil moisture, must be considered. In conditions of low moisture, for example, stomates may close, preventing ozone uptake. Ozone peak concentrations exceeding 100 ppb are also considered to be important in inducing injury and the number of hours in a year above 100 ppb may be significant for evaluating risk.

Atmospheric Deposition Parameters

Atmospheric deposition is the process by which airborne particles and gases are deposited to the earth's surface either through wet deposition (rain or snow), occult deposition (cloud or fog), or as a result of complex atmospheric processes such as settling, impaction, and adsorption, known as dry deposition. Although it is important to know total deposition, (i.e., the sum of wet, occult, and dry deposition) to park ecosystems, often only the wet deposition component is known, as it is the only one that is monitored routinely and extensively across the U.S. (at over 200 sites), as part of the National Atmospheric Deposition Program (NADP). Dry deposition is monitored at about 70 sites as part of the Clean Air Status and Trends Network (CASTNet). Clouds and fog may contribute significantly to total deposition at certain locations (e.g., high elevation areas and areas that experience a high frequency of clouds and fog), but monitoring cloud and fog deposition is difficult and is done at only a couple of locations in the U.S. Acids, nutrients, and toxics are the primary compounds within deposition that are of concern in park ecosystems.

Deposition can be expressed as concentration (e.g., micrograms per cubic meter or milligrams per liter) or deposition rates (e.g., kilograms per hectare per year – kg/ha/yr). Deposition rates are included in Air Atlas summaries, as these rates best characterize the amount of deposition an ecosystem experiences.

NADP dep (kg/ha/yr): pollutant ions in wet deposition from rain or snow are measured by the National Atmospheric Deposition Program (NADP) and expressed as kg/ha/yr. NADP measures

a comprehensive suite of anions and cations; deposition rates of total wet sulfur (S) and total wet inorganic nitrogen (N) (ammonium plus nitrate ions) are included in the summaries.

NADP Total S (kg/ha/yr): total sulfur from sulfate ions in wet deposition.

NADP Total N (kg/ha/yr): total inorganic nitrogen from ammonium and nitrate ions in wet deposition.

Atmospheric deposition affects ecosystems in a variety of ways, including acidification, fertilization or eutrophication, and accumulation of toxics. Acid deposition from sulfur and nitrogen compounds affects freshwater lakes, streams, and watersheds. Acid deposition effects include changes in water chemistry that affect algae, fish, submerged vegetation, and amphibian and aquatic invertebrate communities. Deposition can also cause changes in soil that affect soil microorganisms, understory plants, and trees. Excess nitrogen deposition can cause unwanted fertilization effects, leading to changes in plant community structure and diversity. In estuaries and coastal waters, nitrogen can cause algae blooms, decreases in dissolved oxygen, and loss of seagrasses (i.e., eutrophication).

All areas of the country are experiencing levels of atmospheric deposition above natural levels. The ability of ecosystems to deal with increased levels of deposition varies widely. High elevation ecosystems in the Rocky Mountains, Cascades, Sierra Nevada, southern California, and eastern U.S. are generally the most sensitive to atmospheric deposition due to their poor ability to neutralize acid deposition. Other sensitive areas include the upper Midwest, New England, and Florida, including the shallow bays and estuaries along the Atlantic and Gulf Coasts. Streams in both Shenandoah and Great Smoky Mountains NPs are experiencing chronic and episodic acidification and brook trout fisheries in Shenandoah have been affected. Rocky Mountain NP is also currently undergoing subtle changes in aquatic and terrestrial ecosystems attributable to atmospheric deposition. In some areas, excess nitrogen deposition has caused shifts in plant species composition, with native species being replaced by invasive and exotic species that are better able to utilize nitrogen.

Visibility Parameters

A number of visibility indices, or measurements, can be used to express visibility conditions. The measurement used in Air Atlas summaries is light extinction.

bextClear: annual average light extinction, expressed in inverse megameters, on the 20 percent clearest days

bextHazy: annual average light extinction, expressed in inverse megameters, on the 20 percent haziest days

Light extinction, expressed in the form of inverse megameters (Mm^{-1}), is proportional to the amount of light lost because of scattering or absorption by particles in the air as the light travels over a million meters (one million meters = one megameter). Light extinction occurs when particles in the air scatter or absorb light; extinction generally increases as particle concentrations in the air increase.

Extinction can be measured directly, with a transmissometer and nephelometer, or it can be calculated from representative aerosol measurements. Air Atlas extinction estimates, so-called “reconstructed” estimates, are calculated from aerosol measurements. Total extinction is the sum of the individual extinctions caused by gases, particles, and air molecules in the atmosphere. Relative humidity, as well as particle concentrations, is considered in the equation, as relative humidity increases the extinction efficiency of certain particles.

Light extinction is averaged for the 20 percent clearest and the 20 percent haziest days in an area. The Environmental Protection Agency’s 1999 Regional Haze Regulations require that reasonable progress be made to restore visibility to natural background conditions within 60 years. States are to establish goals for each Class I area to improve visibility on the haziest days (defined as the 20 percent haziest day) and ensure no degradation occurs on the clearest days (defined as the 20 percent clearest days). Emissions reductions that benefit visibility in Class I areas are also expected to benefit visibility in all other areas.

Visual range (VR) is another index used to describe visibility. Because VR is not particularly useful for assessing the quality of scenic vistas (clarity, color), light extinction is used in Air Atlas. However, VR is sometimes useful for describing visibility to the general public. VR is expressed as length; extinction is expressed as 1/length. The relationship between VR and extinction is:

$$VR = \frac{3.912}{\text{bext}(\text{km}^{-1})} = \frac{3912}{\text{bext}(\text{Mm}^{-1})}$$

MID-ATLANTIC NETWORK

OCTOBER 2004

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE MID-ATLANTIC NETWORK

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator

species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these

concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to -4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE MID-ATLANTIC NETWORK

Park	Code	State	Risk	O3 Data
Appomattox Court House NHP	APCO	VA	moderate	kriged
Booker T. Washington NM	BOWA	VA	moderate	kriged
Eisenhower NHS	EISE	PA	high	kriged
Fredericksburg & Spotsylvania NMP	FRSP	VA	high	kriged
Gettysburg NMP	GETT	PA	high	kriged
Hopewell Furnace NHS	HOFU	PA	high	kriged
Petersburg NB	PETE	VA	moderate	kriged
Richmond NBP	RICH	VA	moderate	kriged
Shenandoah NP	SHEN	VA	moderate	monitored
Valley Forge NHP	VAFO	PA	high	kriged

A portion of the Appalachian National Scenic Trail passes through the network. A stand-alone assessment of risk has been produced for sites along the Appalachian Trail.

APPOMATTOX COURT HOUSE NATIONAL HISTORIC PARK (APCO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for APCO					
	1995	1996	1997	1998	1999
Sum06	17	16	21	26	30
W126	34.6	27.9	42.1	57.2	41.5
N60	643	523	758	1040	750
N80	77	50	114	212	131
N100	5	4	9	27	9

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at APCO					
	1995	1996	1997	1998	1999
Month 1	6.78	0.26	-2.18	-0.88	-2.56
Month 2	-0.32	-0.32	0.60	-2.82	-1.22
Month 3	-2.45	1.89	-0.09	-0.71	-1.80

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at APCO					
	1995	1996	1997	1998	1999
April	-2.57	-1.21	1.43	1.98	-0.55
May	1.17	1.53	-2.18	2.25	-1.93
June	6.78	0.26	0.60	-0.88	-2.56
July	-0.32	-0.32	-0.09	-2.82	-1.22
August	-2.45	1.89	-1.19	-0.71	-1.80
September	-0.68	7.05	0.42	-2.84	5.84
October	2.76	0.16	-0.62	-2.38	-0.64

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in several years. These levels of exposure can injure vegetation in the higher ozone years.
- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1999, experienced three months of mild and moderate drought. The three intermediate ozone years had one month of moderate drought each, and the year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure, although the pattern is not consistent. In the highest ozone year, 1998, there were three months of moderate drought. The next two lower exposure years, 1997 and 1999, had two and four

months of mild and moderate drought, respectively. The second lowest exposure year had two months of moderate drought, and the lowest year had one month of mild drought.

The risk of foliar ozone injury at Appomattox Court House National Historic Park is moderate. The threshold level for injury is consistently satisfied by the Sum06 index and generally by the W126 index. The N-values indicate there are significant exposures to concentrations of ozone greater than 80 and 100 ppb in some years, and considerably reduced exposure in other years. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood that the exposures will produce foliar injury. The probability of foliar injury developing may be greatest during years such as 1997 when ozone levels exceed thresholds, and soil moisture levels do not place long-term constraints on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, American elder, crownbeard, and northern fox grape.

BOOKER T. WASHINGTON NATIONAL MONUMENT (BOWA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126

exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BOWA					
	1995	1996	1997	1998	1999
Sum06	19	17	23	24	26
W126	35.4	29.1	42.5	60.8	43.5
N60	677	527	769	1089	812
N80	66	51	108	232	137
N100	3	5	6	29	10

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BOWA					
	1995	1996	1997	1998	1999
Month 1	-0.32	1.53	0.60	-2.82	-2.56
Month 2	-2.45	0.26	-0.09	-0.71	-1.22
Month 3	-0.68	-0.32	-1.19	-2.84	-1.80

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BOWA					
	1995	1996	1997	1998	1999
April	-2.57	-1.21	1.43	1.98	-0.55
May	1.17	1.53	-2.18	2.25	-1.93
June	6.78	0.26	0.60	-0.88	-2.56
July	-0.32	-0.32	-0.09	-2.82	-1.22
August	-2.45	1.89	-1.19	-0.71	-1.80
September	-0.68	7.05	0.42	-2.84	5.84
October	2.76	0.16	-0.62	-2.38	-0.64

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in several years. These levels of exposure can injure vegetation in the higher ozone years.
- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1999, experienced three months of mild and moderate drought. The year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. The three intermediate ozone years had one or two months of mild and moderate drought each. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure, although the pattern is not consistent. In the highest ozone year, 1998, there were three months of moderate drought. The three intermediate ozone years, 1997, 1999 and 1995, had two to four months of mild and moderate drought. In the lowest ozone year, 1996, there was one month of mild drought.

The risk of foliar ozone injury at Booker T. Washington National Monument is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, and intermittently by the W126 index. The N-values indicate there are significant exposures to concentrations of ozone greater than 80 and 100 ppb in some years, and considerably reduced levels of exposure in other years. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood that the exposures will produce foliar injury. The probability of foliar injury developing may be greatest during years such as 1997

when ozone levels exceed thresholds, and soil moisture levels do not place long-term constraints on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, white ash, yellow-poplar, American sycamore, black cherry, and American elder.

EISENHOWER NATIONAL HISTORIC SITE (EISE)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for EISE					
	1995	1996	1997	1998	1999
Sum06	20	20	25	32	33
W126	39.5	32.1	44.2	59.4	48.5
N60	651	573	749	1007	812
N80	168	87	160	270	199
N100	23	6	21	32	23

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at EISE					
	1995	1996	1997	1998	1999
Month 1	2.52	4.42	-1.49	0.10	-2.02
Month 2	2.25	4.57	-0.64	-0.64	-2.40
Month 3	-2.09	0.38	-0.21	-2.42	-2.98

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at EISE					
	1995	1996	1997	1998	1999
April	-1.43	0.35	-2.05	1.39	0.68
May	0.05	1.37	-0.52	1.00	-2.02
June	2.52	4.42	-1.49	1.01	-2.40
July	2.25	4.57	-0.64	0.10	-2.98
August	-2.09	0.38	-0.21	-0.64	-0.41
September	-0.55	5.89	1.42	-2.42	4.11
October	2.22	2.17	-1.37	-0.89	0.19

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in most years. These levels of exposure can injure vegetation.
- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1999, had three months of moderate drought. The three intermediate years covered a wide range of exposure values, but each had only one month of drought. The lowest exposure year, 1996, had favorable conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure, and the pattern is again not consistent. The highest ozone year, 1998, experienced one month of moderate drought. The next two highest ozone years, 1999 and 1997, had similar levels of exposure and three months of mild and moderate drought each. There were two months of drought in the second lowest year, and the lowest ozone year, 1996, had favorable soil moisture conditions.

The risk of foliar ozone injury to plants at Eisenhower National Historic Site is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are generally high. While the levels of ozone exposure consistently create the potential for injury, the largely inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing is greatest during years such as 1996 and 1998 when

ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under limited drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, and black cherry.

FREDERICKSBURG & SPOTSYLVANIA NATIONAL MILITARY PARK (FRSP)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FRSP					
	1995	1996	1997	1998	1999
Sum06	24	26	30	37	38
W126	34.7	31.0	38.6	49.1	46.6
N60	613	567	660	831	777
N80	121	79	141	212	215
N100	16	3	17	36	26

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FRSP					
	1995	1996	1997	1998	1999
Month 1	0.11	-0.73	-0.02	-2.74	-1.80
Month 2	-2.62	1.51	0.79	-2.87	-0.95
Month 3	-0.54	0.72	-1.63	-2.28	-1.34

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FRSP					
	1995	1996	1997	1998	1999
April	-1.62	-0.63	1.01	1.37	-0.75
May	1.57	0.66	-2.03	0.29	-1.51
June	3.93	-0.73	-0.02	0.24	-1.80
July	0.11	1.51	0.79	-2.74	-0.95
August	-2.62	0.72	-1.63	-2.87	-1.34
September	-0.54	3.99	-0.88	-2.28	7.71
October	3.44	2.23	-0.19	-2.46	-0.22

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations of 60 and 80 ppb are generally elevated, and exceeded 100 ppb for a significant number of hours in most years. These levels of exposure can injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure values, 1999 and 1998, experienced two and three months, respectively, of moderate or mild drought. The two mid-level ozone years each had one month of drought, and the year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. In the highest ozone year, 1998, there were four months of moderate drought. The three intermediate ozone years each had two months of mild and

moderate drought. In the lowest ozone year, 1996, soil moisture was favorable throughout.

The risk of foliar ozone injury at Fredericksburg and Spotsylvania National Military Park is high. The threshold level for injury is consistently satisfied by the Sum06 index and generally by the W126 index. The N-values indicate there are significant exposures to concentrations of ozone greater than 80 and 100 ppb in most years, and considerably reduced exposure in others. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood the exposures will produce foliar injury. Annual variations in ozone exposure and soil moisture interact to create highly variable levels of risk. The probability of foliar injury developing is greatest during years such as 1995 and 1997 when ozone levels exceed thresholds, and soil moisture levels do not place long-term constraints on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, and Allegheny blackberry.

GETTYSBURG NATIONAL MILITARY PARK (GETT)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GETT					
	1995	1996	1997	1998	1999
Sum06	21	21	26	32	33
W126	39.5	32.1	43.7	57.9	47.5
N60	648	571	734	977	791
N80	172	90	165	266	199
N100	26	7	24	32	25

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GETT					
	1995	1996	1997	1998	1999
Month 1	2.52	4.42	-1.49	0.10	-2.02
Month 2	2.25	4.57	-0.64	-0.64	-2.40
Month 3	-2.09	0.38	-0.21	-2.42	-2.98

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GETT					
	1995	1996	1997	1998	1999
April	-1.43	0.35	-2.05	1.39	0.68
May	0.05	1.37	-0.52	1.00	-2.02
June	2.52	4.42	-1.49	1.01	-2.40
July	2.25	4.57	-0.64	0.10	-2.98
August	-2.09	0.38	-0.21	-0.64	-0.41
September	-0.55	5.89	1.42	-2.42	4.11
October	2.22	2.17	-1.37	-0.89	0.19

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, but the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The two highest Sum06 ozone years had similar levels of exposure, but different soil moisture regimes. The year with the highest exposure, 1999, had three months of moderate drought, while the second highest year, 1998, had one month of moderate drought. The three years with lower ozone exposure had two months of drought among them. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure, and the pattern is again not consistent. The highest ozone year, 1998, experienced one month of moderate drought.

The next two highest ozone years, 1999 and 1997, had three months of mild and moderate drought each. There were two months of drought in the second lowest year, and the lowest ozone year, 1996, had favorable soil moisture conditions.

The risk of foliar ozone injury to plants at Gettysburg National Military Park is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are generally high. While the levels of ozone exposure consistently create the potential for injury, the largely inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under limited drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, and northern fox grape.

HOPEWELL FURNACE NATIONAL HISTORIC SITE (HOFU)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias exaltata</i>	Tall milkweed	Asclepiadaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Aster macrophyllus</i>	Big-leaf aster	Asteraceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus rigida</i>	Pitch pine	Pinaceae
<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HOFU					
	1995	1996	1997	1998	1999
Sum06	29	25	28	29	32
W126	34.6	28.1	34.5	42.5	41.1
N60	556	485	524	686	647
N80	173	106	170	215	206
N100	36	13	38	28	45

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HOFU					
	1995	1996	1997	1998	1999
Month 1	-1.51	1.51	-1.33	-1.18	-2.41
Month 2	0.10	3.68	-0.12	-1.24	-4.16
Month 3	-3.35	0.21	-0.50	-2.27	-0.58

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HOFU					
	1995	1996	1997	1998	1999
April	-1.83	1.58	-1.67	1.26	-0.39
May	0.13	0.02	-0.25	0.98	-1.74
June	-1.51	1.51	-1.33	1.69	-2.41
July	0.10	3.68	-0.12	-1.18	-4.16
August	-3.35	0.21	-0.50	-1.24	-0.58
September	-0.49	1.93	-0.77	-2.27	7.56
October	4.01	4.32	-1.32	0.10	1.08

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. However, soil moisture levels during the 90-day accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, but the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 ozone exposure value experienced two months of mild and severe drought. The two years with the same, second highest exposure, 1995 and 1998, had two months of mild and severe and three months of mild and moderate drought, respectively. The year with the

second lowest exposure, 1997, had one month of mild drought, and the lowest exposure year, 1996, had favorable soil moisture conditions. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone exposure. The two years with the highest exposure levels, 1998 and 1999, experienced three sequential months of mild and moderate drought. The two intermediate ozone years, 1995 and 1997, had three months of intermittent mild or severe drought, while the lowest ozone year, 1996, had favorable soil moisture conditions throughout.

The risk of foliar ozone injury to plants at Hopewell Furnace National Historic Site is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, and northern fox grape.

PETERSBURG NATIONAL BATTLEFIELD (PETE)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Philadelphus coronarius</i>	Sweet mock-orange	Hydrangeaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PETE					
	1995	1996	1997	1998	1999
Sum06	25	24	35	38	35
W126	32.6	28.5	44.0	48.7	42.6
N60	570	514	745	843	711
N80	97	65	174	187	180
N100	11	3	24	27	26

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PETE					
	1995	1996	1997	1998	1999
Month 1	0.65	1.68	-1.25	0.99	-1.18
Month 2	-1.60	4.40	0.98	0.04	-0.87
Month 3	-3.52	1.67	-2.69	-2.05	-0.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PETE					
	1995	1996	1997	1998	1999
April	-1.31	0.58	1.17	0.53	-0.26
May	0.63	0.55	-1.61	0.99	-2.33
June	0.65	1.68	-1.25	0.04	-1.18
July	-1.60	4.40	0.98	-2.05	-0.87
August	-3.52	1.67	-2.69	-2.06	-0.97
September	-0.40	1.93	-2.29	-1.42	4.84
October	1.69	3.11	0.28	-2.31	3.15

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours almost every year. These levels of exposure can injure vegetation.
- Ozone exposure levels for the 90-day Sum06 accumulation periods were high and relatively uniform over the five years, and soil moisture conditions showed scattered months of mild to severe drought stress. There was no apparent association between the Sum06 index of ozone exposure and soil moisture. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the highest ozone year, 1998, there were four months of mild and moderate drought. The two next highest ozone years, 1997 and 1999, had four and two months of mild and moderate drought, respectively. The lowest ozone year had

favorable conditions, but the second lowest year, 1995, had three months of mild and severe drought.

The risk of foliar ozone injury to plants at Petersburg National Battlefield is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in one year. The generally inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are two to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. However, years such as 1999, in which high levels of exposure occur under conditions of less severe drought, may have the potential to produce foliar injury. The probability of foliar injury developing may greatest during years such as this when ozone levels are elevated, and soil moisture levels are under mild drought and do not create a long-term constraint on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, crownbeard, and northern fox grape.

RICHMOND NATIONAL BATTLEFIELD PARK (RICH)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for RICH					
	1995	1996	1997	1998	1999
Sum06	26	27	36	40	37
W126	33.9	29.9	44.3	50.6	44.8
N60	588	540	739	860	743
N80	111	74	183	209	201
N100	13	3	26	34	31

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at RICH					
	1995	1996	1997	1998	1999
Month 1	0.65	1.68	-1.25	0.99	-1.18
Month 2	-1.60	4.40	0.98	0.04	-0.87
Month 3	-3.52	1.67	-2.69	-2.05	-0.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at RICH					
	1995	1996	1997	1998	1999
April	-1.31	0.58	1.17	0.53	-0.26
May	0.63	0.55	-1.61	0.99	-2.33
June	0.65	1.68	-1.25	0.04	-1.18
July	-1.60	4.40	0.98	-2.05	-0.87
August	-3.52	1.67	-2.69	-2.06	-0.97
September	-0.40	1.93	-2.29	-1.42	4.84
October	1.69	3.11	0.28	-2.31	3.15

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours almost every year. These levels of exposure can injure vegetation.
- There was no apparent association between the 90-day Sum06 index of ozone exposure and soil moisture. Ozone exposure levels for the Sum06 accumulation periods varied moderately among the five years, and soil moisture conditions showed scattered months of mild to severe drought stress. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the highest ozone year, 1998, there were four months of mild and moderate drought. The two next highest ozone years, 1997 and 1999, had four and two months of mild and

moderate drought, respectively. The lowest ozone year had favorable conditions, but the second lowest year, 1995, had three months of mild and severe drought.

The risk of foliar ozone injury to plants at Richmond National Battlefield Park is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in one year. The generally inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are two to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. However, years such as 1999, in which high levels of exposure occur under conditions of less extensive drought, have the greatest potential to produce foliar injury. The probability of injury developing may greatest during years when ozone levels are elevated, and soil moisture levels are under limited drought and do not produce long-term constraints on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, American elder, crownbeard, and northern fox grape.

SHENANDOAH NATIONAL PARK (SHEN)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Pinus rigida</i>	Pitch pine	Pinaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Pinus virginiana</i>	Virginia pine	Pinaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae
<i>Verbesina occidentalis</i>	Crownbeard	Asteraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SHEN					
	1995	1996	1997	1998	1999
Sum06	33	31	29	57	43
W126	73.1	63.7	65.5	118.3	69.4
N60	1454	1268	1239	2321	1307
N80	134	55	123	387	231
N100	1	0	4	67	11

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SHEN					
	1995	1996	1997	1998	1999
Month 1	-0.52	2.64	0.60	-2.56	-2.03
Month 2	-1.56	1.73	0.15	-2.57	-1.60
Month 3	-0.68	3.13	-1.30	-2.87	6.55

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SHEN					
	1995	1996	1997	1998	1999
April	-1.59	-0.67	-1.04	0.61	-1.17
May	0.83	2.64	-1.55	1.10	-1.96
June	3.57	1.73	0.60	2.27	-2.42
July	-0.52	3.13	0.15	-2.56	-2.03
August	-1.56	1.41	-1.30	-2.57	-1.60
September	-0.68	7.58	1.02	-2.87	6.55
October	2.43	1.00	-1.00	-2.22	-0.47

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only two years, and thus the criteria for injury under the W126 exposure index are generally not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a few hours most years and for a significant number of hours in one year. The higher levels of exposure can injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest Sum06 exposure year, 1998, there were three months of moderate drought stress, and two months of drought in the second highest ozone year, 1999. The three lowest ozone years had similar levels of exposure, with two of the years each having one month of mild drought. Soil moisture levels associated with the W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. There were four months of moderate drought in the highest ozone year, 1998, and two months of mild drought in the second highest year, 1995. The median exposure year, 1999, had five months of mild and moderate drought.

The lowest ozone year, 1996, had favorable soil moisture conditions, while the second lowest year, 1997, had four months of mild drought.

The risk of foliar ozone injury at Shenandoah National Park is moderate. The threshold for injury is consistently satisfied for the Sum06 and occasionally the W126 indices. The N-values indicate that there are frequent exposures to concentrations of ozone greater than 80 ppb. There are several hours of exposure to 100 ppb in most years, and a significant number of hours of exposure in some years. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood that the higher exposures will produce foliar injury. The probability of foliar injury developing may be greatest during years when ozone levels exceed thresholds, and soil moisture levels do not place long-term constraints on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, cut-leaf coneflower, American elder, crownbeard, and northern fox grape.

VALLEY FORGE NATIONAL HISTORIC PARK (VAFO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Philadelphus coronarius</i>	Sweet mock-orange	Hydrangeaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Vitis labrusca</i>	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for VAFO					
	1995	1996	1997	1998	1999
Sum06	31	26	27	29	32
W126	35.8	28.8	34.0	41.5	40.7
N60	574	498	512	670	633
N80	187	122	170	211	209
N100	44	17	39	30	52

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the

park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at VAFO					
	1995	1996	1997	1998	1999
Month 1	-1.51	1.51	-1.33	-1.18	-2.41
Month 2	0.10	3.68	-0.12	-1.24	-4.16
Month 3	-3.35	0.21	-0.50	-2.27	-0.58

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at VAFO					
	1995	1996	1997	1998	1999
April	-1.83	1.58	-1.67	1.26	-0.39
May	0.13	0.02	-0.25	0.98	-1.74
June	-1.51	1.51	-1.33	1.69	-2.41
July	0.10	3.68	-0.12	-1.18	-4.16
August	-3.35	0.21	-0.50	-1.24	-0.58
September	-0.49	1.93	-0.77	-2.27	7.56
October	4.01	4.32	-1.32	0.10	1.08

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. However, soil moisture levels during the 90-day periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the three highest ozone exposure values, 1999, 1995 and 1998, experienced two, two and three months of mild to severe drought, respectively. The two years with the lowest ozone exposure, 1996 and 1997, had one month of mild drought between them. Soil moisture levels associated with the seasonal

W126 index also appear inversely related to ozone exposure. In each of the two highest ozone years, 1998 and 1999, there were three consecutive months of mild to severe drought. The two mid-level ozone years, 1995 and 1997, had three interspersed months of mild to severe drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Valley Forge National Historic Park is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in higher ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, and northern fox grape.